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FOREST ROAD DESIGN TO MINIMIZE EROSION IN THE SOUTHERN APPALACHIANS

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ABSTRACT

Excessive erosion and low serviceability of roads are continuing problems associated with forest management in the mountains of the southeastern United States. Road and erosion research at Coweeta Hydrologic Laboratory in western North Carolina dates from roadbank stabilization work in the 1930's. Emphasis has been to develop and demonstrate a low-cost, low-maintenance road design. Results cover such features as: drainage and the broad-based dip, cut-bank design and stabilization, roadbed surfacing, brush barriers and filter strips, culvert sizing, and transportation planning. Application of knowledge gained permits roads to be built and maintained at lower cost while providing practical control of sediment input to streams.

INTRODUCTION

The Regional Guide for the South (USDA 1984*b*) recognizes that roads and skid trails are the major sources of sediment from forestry related activities. The overall environmental impact statement for Region 8 (USDA 1984*a*) estimates an existing National Forest road network of 31,000 mi with approximately 125 mi of new construction or reconstruction each year. About 70% of this annual increment is classed as "local road," the low-standard, limited-use road that is at the end of a transportation system and usually developed for access to timber sales. More than 40 years of road studies and land management demonstrations at Coweeta Hydrologic Laboratory show both an early recognition that roads were a potential problem and a continuing effort to describe the magnitude of soil loss and develop technologies to control it. This paper summarizes the results of Coweeta research and demonstrations. A more complete review of this work will appear in the Coweeta 50th Anniversary Symposium volume.

An exploitive logging demonstration at Coweeta, using roading and skidding practices typical for the 1940's, illustrated the magnitude of the road problem and focused the direction for future studies. Erosion and stream sedimentation were clearly demonstrated and traceable to the road and skid trail system. Haul roads paralleled and crisscrossed the stream while skid trails were steep and often followed intermittent storm channels. Few attempts were made to drain storm waters off the

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transportation system or away from streams. Surfacing stone and revegetation were not used and maintenance consisted simply of reopening access routes blocked by erosion.

Through a series of tests and demonstrations of logging roads in North Carolina, Virginia, and Georgia, a design was developed and promoted for intermittent-use forest access roads. The goal was a simple design that could be marked on the ground and constructed without expensive surveys or detailed specifications. In addition to reduced construction costs, this access road was to be essentially self-maintaining or servicable with extended maintenance intervals (Hewlett and Douglass 1968). Many features from this Coweeta road research are found in Forest Service and industry standards and in state guidelines for Best Management Practices. "Minimum standard" road guidelines developed and promoted by the Timber and Watershed Laboratory in Parsons, West Virginia, represent an allied effort for the central Appalachians (Kochenderfer *et al.* 1984).

ACCESS ROAD CRITERIA

Two means for improving road design to protect water quality are: (1) to keep soil disturbance away from flowing and intermittent stream channels, and (2) to remove water from the roadway with minimal erosion. Roads built on the contour or with gentle grades will traverse the face of a mountain slope, crossing streams with the least disturbance rather than lying parallel to them.

Stream crossings

Each flowing and intermittent stream should be crossed with corrugated pipe or bridge, preferably at a right angle. If the road elevation is lowered at the crossing, the size of the fill is reduced and flood waters resulting from blocked drainage would be prevented from following the road. Culvert size from standard tables may be overly generous. Safety factors used in compiling tables are appropriate for streams draining disturbed landscapes rather than forest floors with high infiltration rates. Capitalizing on the large amount of streamflow data from small watersheds at Coweeta, Douglass (1974) developed frequency relationships between flood flows and area and elevation of the watershed. These equations can be used to select culvert and bridge sizes to handle floods with various recurrence intervals from 2.33 to 50 years. Results agree with and overlap flood frequency equations presented by Jackson (1976) and Whetstone (1982) for mountain, Piedmont, and Coastal Plain regions of North and South Carolina. Larger structures are indicated for the shallow-soiled watersheds of the central Applachians (Helvey 1981).

Guidelines sometimes require that culverts be removed from intermittent-use roads when they are closed. Although digging out a culvert may block access, it is an extra and possibly unnecessary disturbance to the stream. The stream crossing is the most critical section of road influencing water quality. During, and for some time after construction, raw and exposed fill reaches into the channel. Dips and ditchlines may reduce the volume of storm water flowing across the fill but until the loose soil is vegetated, the stream is at risk. Early grassing and spreading brush or erosion-resisting fabrics on exposed soil at stream crossings is imperative. Figure 1 shows the cumulative amount of soil placed in a small stream during the construction period and again during yarding and hauling operations a year later (Swank *et al.* 1982). The road continued to be used during the rest of the time, but soil losses were much less because the edge of the roadbed and the fill were protected by a healthy stand of grass.

Surface drainage

The object is to remove storm waters from the roadbed before the flow gains enough volume and velocity to seriously erode the surface. The next step is to dispose of these waters where they will infiltrate and drop their sediment load rather than carrying it to the stream.

Outsloping the roadbed serves to keep water from flowing next to and undermining the cut bank and is intended to spill water off the road in many random sites in small volumes. However, traffic will rut a soft roadbed and prevent outsloping from being effective. Also, berms form along the edge of older roadbeds and block drainage. But during construction and until loose fill was protected by vegetation, a berm purposely left on the outside edge of an outsloped road eliminated fill erosion (Swift 1984*b*).

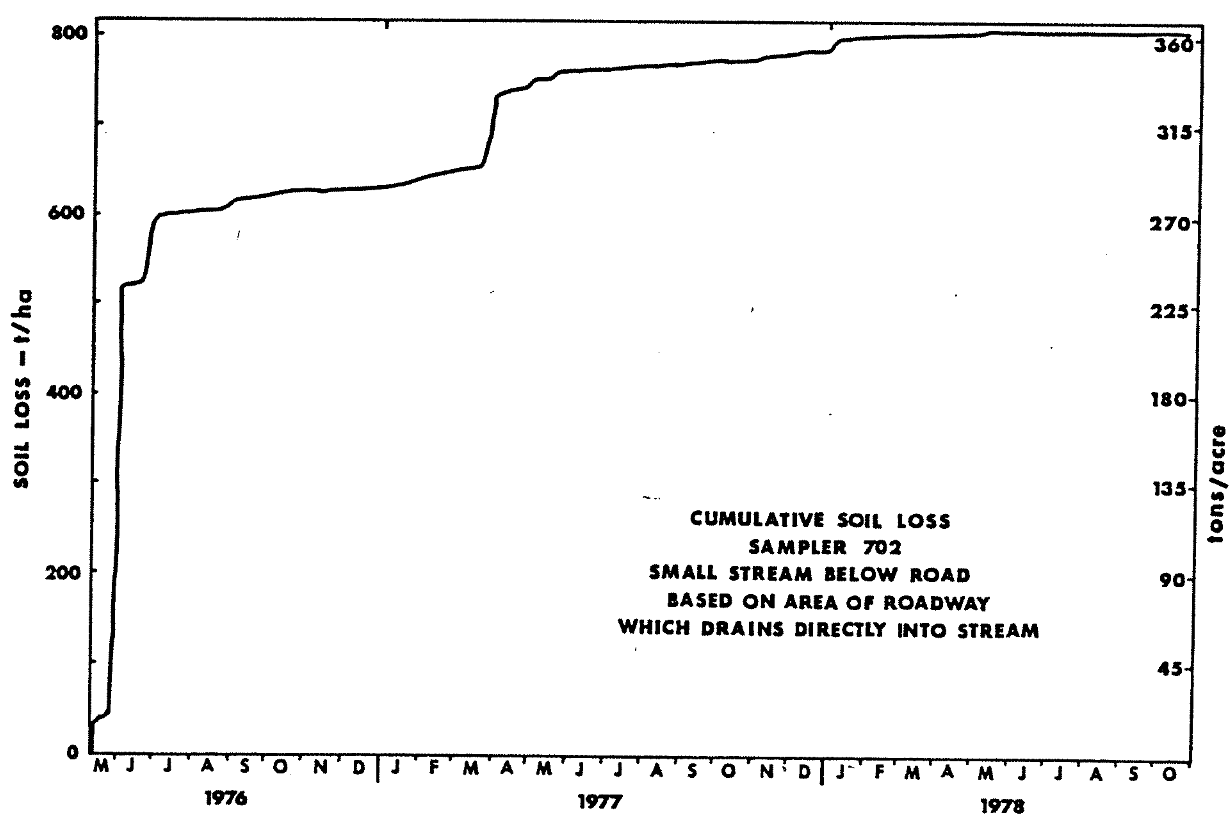

Figure 1. Cumulative soil loss from a forest road at a stream crossing during the first 2.5 years after construction began.

In addition to outsloping the roadbed, a short reverse grade should be constructed to turn water off the surface. Open-top culverts and waterbars have been used to divert storm water, but they can quickly fill with sediment and are troublesome to maintain. The broad-based dip (Fig. 2) was designed to be a relatively permanent and self-maintaining water diversion structure that can be traversed by any vehicle (Hewlett and Douglass 1968).

Dip spacing is a function of road grade; the steeper the slope, the shorter the distance between dips. Experience has demonstrated that dips are difficult to construct and maintain on steep grades and National Forest practice now is to restrict dips to grades less than 8 to 10 percent. The updated dip spacing equation in Fig. 2 is based upon observations of functioning structures on roads in the southern Appalachians.

The spacing of dips may also be determined by needs for drainage in specific locations. Water should be diverted from the road surface at the head of a steep grade and on either side of a stream crossing. Sometimes natural breaks in grade can be used for dips and a well-drained contour road can have a gently rolling centerline without sharply defined dips. Dips should be placed so that storm water and sediment are spread on convex surfaces away from drainage channels rather than dumped into places where sediment can be picked up and carried to the stream system.

The bottom of a dip tends to collect sediment during small storms. Larger storms may flush the dip but traffic tends to push this moist sediment into a barrier that blocks drainage and eventually turns the bottom of the dip into a mudhole. Grass growing at the outlet of a dip will trap sediment and block drainage. Experience demonstrates that dip outlets should be cleaned every 2 to 7 years, depending on traffic and storm frequency. Spot applications of gravel in and on the approaches to a dip will improve trafficability.

Field testing has shown that maintenance practices must be modified for roads with broad-based dips. For example, a motor-grader is designed to smooth the road surface and its use often results in filling the dips. Wide-bladed road equipment may disturb stabilized cut slopes, particularly on narrow intermittent-use roads. In Coweeta's experience, small dozers or front-end loaders have been the best equipment for maintaining a dipped road.

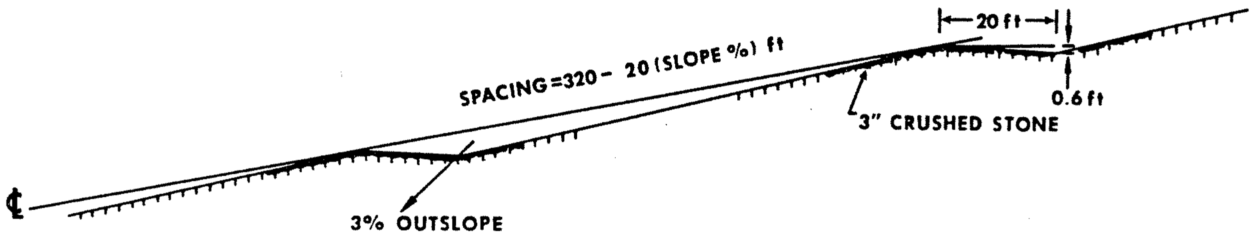

Figure 2. Diagram of the broad-based dip design for forest access roads.

For steeper grades and where road cuts intercept subsurface flow, inside ditches and culverts are required. From the standpoint of water quality, inside ditches should be avoided whenever possible. By its very nature, the ditchline is a man-made gully which must be disturbed by cleaning to maintain drainage. Often, more water is collected in a ditch than by individual dips, and this larger volume of water carries more sediment and reaches the stream system easier.

Filter strips

The outsloped road design with broad-based dip drainage helps insure that most of the sediment-laden storm water is dispersed onto the forest floor rather than into a stream. If the forest floor is protected by litter and a root mat and has the high infiltration rates typical of Appalachian Mountain soils, then sediment is trapped. An important consideration is the distance downslope that sediment deposits cover the forest floor. To protect water quality, this distance should be less than the width of filter strip reserved between road and stream.

Improved road construction methods allow reductions in filter strip widths from past guidelines if certain practices are followed. A survey of 2.1 mi of newly constructed forest roads in the vicinity of Coweeta identified 76 sediment deposits longer than 20 ft (Swift *in press*). The longest three deposits extended over 260 ft downslope but these were in the portion of road that was left unfinished and ungrassed throughout winter (Fig. 3). Best Management Practice guidelines for moderate erosion hazard soils call for a filter strip of 274 ft on a 60% slope. Where the road was finished and cuts and fills grassed before winter, measured deposits were all less than 150 ft long, even on slopes over 60%. Furthermore, brush barriers at the toe of fills held the longest deposits under 155 ft on bare fills and under 75 ft if fills were vegetated. In a prescribed burn, the lack of both forest litter and brush barrier allowed sediment to move up to 200 ft on a 60% slope. These results emphasize that mitigating practices will reduce movement of sediment downslope, thus allowing greater flexibility when selecting road locations. Again, the stream crossing is a critical point because the filter strip narrows to zero and the opportunities for mitigating practices are limited.

Sources of road sediment

Soil loss rates differ among cut slopes, fill slopes, and roadbeds and are influenced by season and vegetation. Predictably, a graveled roadbed with well-grassed slopes has the lowest soil loss (Swift 1984*a*). Without any grass cover in early winter, freeze and thaw cycles loosen the cut slopes and large amounts of soil can accumulate at the toe of the slope. Without an inside ditch, the debris stabilizes and contributes little to sediment leaving the roadway. With a ditch, however, road maintenance and storm runoff move the loose soil offsite, undercut the newly formed debris pile, and increase the potential for further soil loss. For example, in 4 winter months, 67 to 160 tons/acre were lost from a pair of ungrassed cut slopes. After grassing, soil loss was negligable (Swift 1984*b*). These banks were backsloped about 3/4:1.

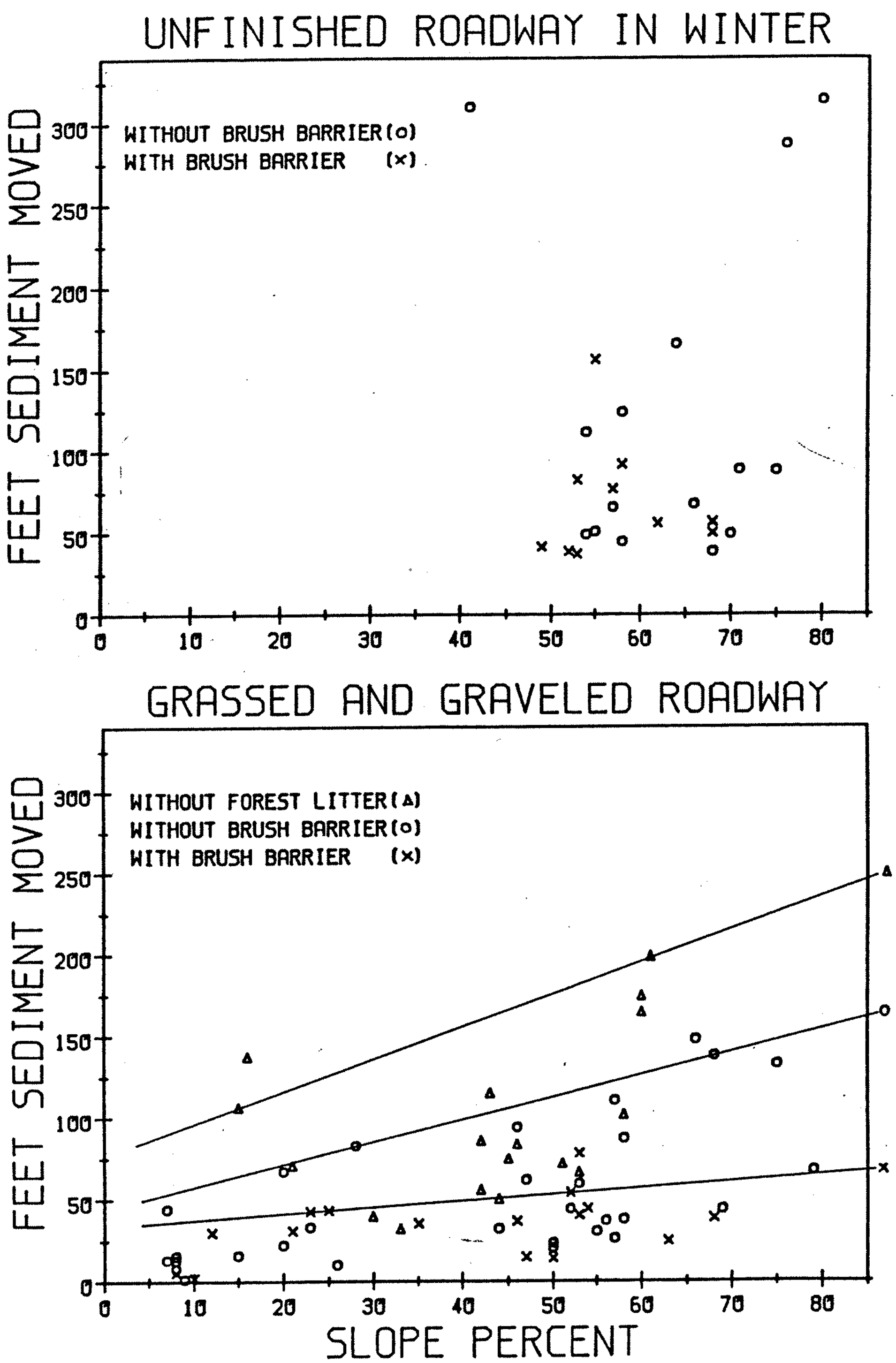

Figure 3. Lengths of sediment deposits downslope from roads are greatest where roadway is unprotected by vegetation and least where brush barriers and forest litter trap sediment flows. Lines enclose 95% of points in each category.

On other roads at Coweeta without inside ditches, vertical cut slopes were demonstrated (Hewlett and Douglass 1968). Vertical cuts are less expensive because less right-of-way clearing is required, less soil is moved, and smaller fills created. Cut bank soils will slump to the angle of repose, often carrying roots, seeds, litter, and topsoil to vegetate the exposed surface. At Coweeta, vertical cuts up to 6 ft deep have stabilized naturally on moist sites, but 4 ft seems to be the limit on dry, infertile, south-facing banks. Although a narrow right-of-way lowers construction costs, other factors argue for wider road clearings. For example, "daylighting" accelerates the drying of roadbeds in winter or wet weather (Kochenderfer 1970) and wider roadside areas may be developed as linear wildlife openings (Arney and Pugh 1983).

Hursh (1935,1938,1939,1942) pioneered the use of forest litter, cut weeds, and brush to stabilize high cut banks on new highways through the mountains. Materials were held in place with poles and stakes cut from roadside woods. The mulch broke the eroding force of raindrops, halted the sloughing due to frost action, and encouraged growth of planted or naturally seeded vegetation.

Fill slopes in the Coweeta studies, although uncompacted and unvegetated, eroded only where storm runoff from the road surface, culvert outlets, or dips flowed over loose soil. In early spring, when soil moisture content was high, fills slumped onto the forest floor or downslope against an obstruction such as a brush barrier. Size of fill, steepness of terrain, and texture of soil influence slump occurrence and how far soil moves. Slumps were fewer in number and smaller in volume where slopes were well grassed before winter.

Less soil was lost on a unit area basis from an ungraveled roadbed (less than 8% grade) than from either cut or fill slopes (Swift 1984*b*). After graveling, the small roadbed soil loss came from storm water flowing in ruts or along the lightly graveled shoulder.

Typically, most of the soil lost during the life of a road is lost in that short period from beginning of construction until grass becomes well established and the roadbed is graveled or compacted. Three-quarters of the soil loss measured in 2.5 years in a stream immediately below a road crossing was carried in the first 2 months (Fig. 1).

Roadbed surfacing

Gravel surfacing is the largest single cost item for forest roads; consequently, lower standard, intermittent-use roads often receive only thin coatings of gravel, spot treatments, or no gravel at all. Soils with high coarse fragment content, such as occur in some roads in the central Applachians (Kochenderfer *et al.* 1984), can develop a natural gravel surfacing after an initial loss of finer soil particles. Test sections on a collector-class road at Coweeta (Swift 1984*a*) showed that soil loss from a lightly graveled road was equivalent to loss from an ungraveled one (Fig. 4). In contrast, soil loss from a grassed roadbed was half that of the bare soil roadbed, both carrying the same traffic load. Soil loss from fully graveled roadbeds (6 to 8 in thick) was only 3 to 8% of that from a bare soil roadbed of otherwise similar construction.

Contour roads may suffice without gravel, but climbing access roads on most soils should receive a gravel surface. Compacted, crushed rock with a proper mix of fines is often specified because it will form a tight, smooth surface and, in sufficient depth, carry loaded vehicles. Larger (3-in nominal) washed stone, applied to a freshly worked roadbed, will form a stronger erosion pavement. Although the large stone is a rougher surface than aggregate base course (crusher run), it tends to stay in place and neither wash away nor be thrown or pushed out by traffic.

Transportation planning

One outgrowth of the multiresource management demonstration on Coweeta Watershed 28 (Hewlett and Douglass 1968) was a realization that long-range planning of a forest transportation system should include intermittent-use or local roads as well as fully engineered forest development roads. Land managers have been accustomed to referring to these two broad and sometimes poorly defined classes of roads as temporary and permanent. With the understanding that even the lowest class of road could be a permanent capital investment, came the recognition that preplanning was necessary to

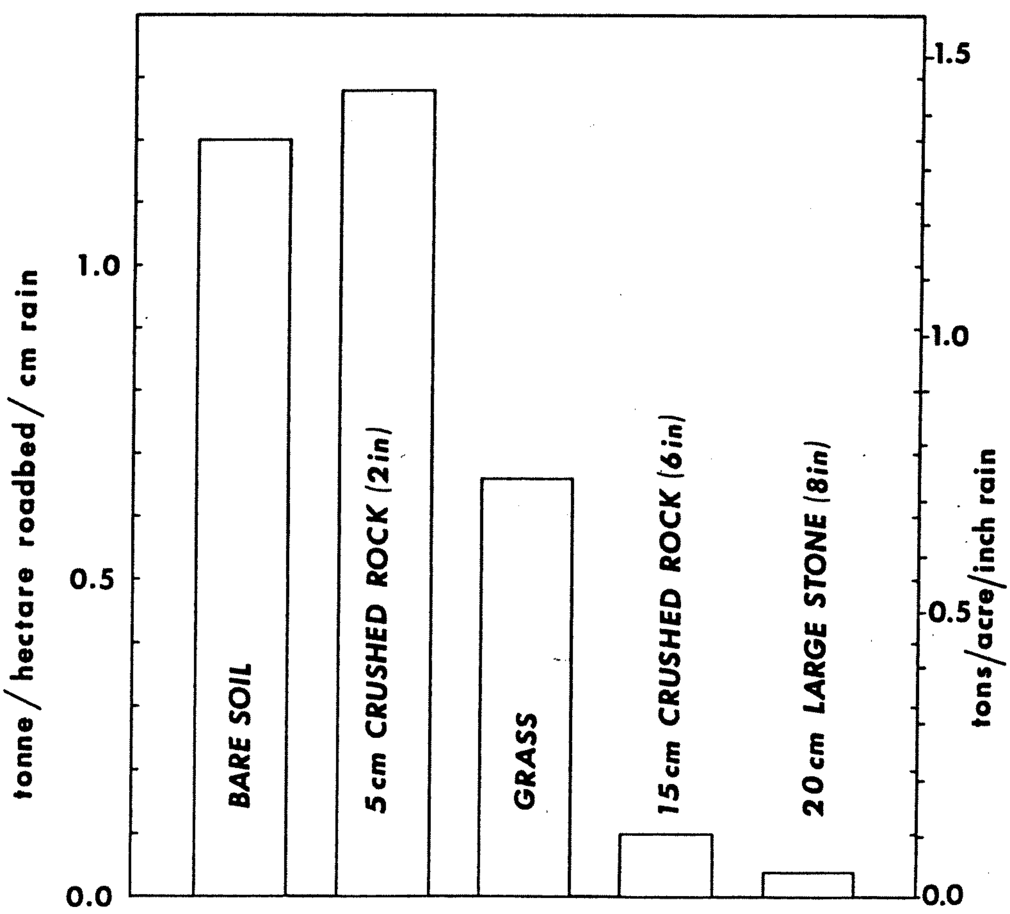

Figure 4. Soil loss rate for roadbeds with five surfacing treatments. Roads all constructed of sandy loam saprolite.

assure that each mile of road is constructed on the best possible location. One technique is to sketch on maps a total road network to serve the planning unit, placing each road section to best serve future management needs while minimizing environmental damage. Avoid past road locations if they do not meet present standards. Then, as management opportunities are exercised, each new piece of road could be built on a site already selected to be the best and most useful. The long-range plan should indicate which roads would be intermittent and closed and which would remain open (either full or part time) and require maintenance. A road in the intermittent category may at some time in the future be upgraded at considerably less cost if it is on a good location and has not washed out.

SUMMARY

The design, construction, and soil loss from forest roads has been an active area of research and demonstration by the Southeastern Forest Experiment Station since Coweeta Hydrologic Laboratory was established. The low-cost, low-maintenance intermittent-use road pioneered by Coweeta is widely accepted and adapted to local conditions by Government and industry land managers and strongly recommended by state agencies with the aim of reducing nonpoint source pollution from forestry activities.

Several principles can be drawn from the Coweeta studies. An inexpensive design and field layout procedure can produce a servicable and environmentally acceptable road. The most effective road system results from a transportation plan developed to serve an entire basin rather than the haphazard sum of individual road projects constructed to serve short-term needs. Soil exposed by construction should be revegetated quickly. Where possible, storm waters should be removed from the road at frequent intervals and in small amounts by outsloping and dips rather than by consolidation into ditchlines and culverts. Contour roads and gentle grades require less maintenance and produce less sediment. Gravel surfacing is best, but a grassed roadbed is acceptable and cheaper where traffic is light and can be controlled to exclude use in wet weather. If only small quantities of gravel are available, it should be applied on climbing grades, poor trafficability soils, and in dips. The stream crossing is the most critical part of the entire road and special efforts should be made to protect and vegetate fill slopes and divert storm waters on the road away from the stream. Filter strips and brush barriers prevent sediment from reaching streams. Unnecessary maintenance must be avoided.

Guidelines for forest road design that minimize the impact of construction and road use on water quality are available for the southern Appalachians. The task now is to increase the application of these guidelines in land management.

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